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The Effects of Variable Flows on Burbot Spawning Migrations in the Kootenai River, Idaho, USA, and Kootenay Lake, British Columbia, Canada, After Construction of the Libby Dam

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Abstract.— Burbot *Lota lota* are at risk of extirpation in the Kootenai River, Idaho, and Kootenay Lake, British Columbia. Burbot fisheries collapsed soon after construction and operation of Libby Dam, in 1972, for flood control and hydropower. Libby Dam changed the river hydrograph and flows are now three to four times higher during winter than in pre-impoundment years but lower in the summer. Burbot are winter spawners and are known to have low swimming endurance. The objective of this investigation was to determine if operation of Libby Dam affected burbot spawning migration. Burbot were captured with baited hoop nets from 1994 through 1998 and each year up to 12 fish were implanted with sonic transmitters to monitor movement. Preliminary study in the winter of 1994–1995 suggested that water management of Libby Dam affected upstream migration of burbot during the spawning period. I then tested the null hypothesis: high winter flow (relative to pre-Libby Dam conditions) for hydropower production/flood control does not disrupt the burbot spawning migration. A conditional agreement was made with the U. S. Army Corps of Engineers and the Bonneville Power Administration to provide three periods of low flow (113 m^3/s) for five consecutive days in each of three replicate tests: November, December, and January. Observations between test days were considered controls (normal winter operation). Three completed flow tests were achieved only for the winter of 1997–1998. Significantly more burbot movement occurred during the low flow tests than the controls and significantly more movement was upstream. I did not detect a difference in the amount of movement between months. No significant difference in the direction of movement was detected between November and December but I found significantly more upstream movement during the January test. Testing also indicated nose velocities measured at burbot locations during the tests were significantly lower than measurements during the controls. These findings suggested that spawning migrations of burbot in the Kootenai River may be disrupted by high flows produced during hydropower production and floodcontrol. Peaking flows probably compound the problems. The disruption to burbot spawning migrations may reduce spawning fitness, reduce stamina, affect vitellogenin synthesis, or disturb spawning synchrony. Any of these factors could be important attributes to the collapse of the burbot population. A management recommendation to recover burbot would be to provide a minimum of 5 weeks of flow similar to pre-Libby Dam conditions, from January through the first week of February, that would provide a favorable migration corridor.

The burbot *Lota lota* is a holarctic freshwater member of the family Gadidae (McPhail and Lindsay 1970). It is found throughout Canada, Alaska and the northern tier of states in the USA. In Idaho, burbot are endemic to the Kootenai River system, but the distribution is contiguous with that in the Kootenai River and Kootenay Lake (a natural lake with a dam at its outlet) in British Columbia (Simpson and Wallace 1970). Burbot once provided important sport and commercial fisheries in the Kootenai basin with an estimated harvest of up to 26,000 fish from the West Arm of Kootenay Lake, British Columbia (Paragamian et al. 2000). The combined average annual catch by the sport and commercial fisheries in Idaho during the 1960s was thought to have exceeded thousands of kilograms. For example the harvest by three commercial fishermen in 1958 was estimated to be over 2,000 kg [Paul Jeppson, Idaho Department of Fish and Game (IDFG) Fisheries Biologist, Panhandle Region archives]. However, soon after completion of Libby Dam on the Kootenai River in Montana by the U. S. Army Corps of Engineers (USACE) in 1972, the two respective fisheries collapsed (Paragamian et al. 2000). Despite increased restrictions on the angler harvest of burbot, neither fishery recovered and each was closed to fishing; the Kootenai River, Idaho, was closed in 1992 and Kootenay Lake and River, British Columbia, in 1997.

The Kootenai system has undergone many anthropogenic alterations (Daley et al. 1981; Northcote 1973; Snyder and Minshall 1996; Anonymous 1996), but many of these changes occurred before the collapse of the burbot fisheries (Paragamian et al. 2000). Paragamian et al. (2000) summarized the case history of the collapse of the burbot fisheries; the most important factor responsible for the decline is thought to be Libby Dam. Operation of Libby Dam for hydropower and flood control during the winter resulted in low flows in summer and high flows in winter and created warmer winter water temperatures (Partridge 1983; Paragamian and Whitman 1998). Winter flows are now more erratic and 300% greater than before [see Paragamian et al. (2000) for a figure of the pre-Libby Dam winter hydrograph]. In addition, Lake Koocanusa, the impoundment created by Libby Dam [see Paragamian et al. (2000) for a figure of the Kootenai River system], acts as a nutrient sink and has reduced productivity of the river (Snyder and Minshall 1996) and that of Kootenay Lake (Daley et al. 1981).

Burbot are winter spawners and are known to travel over 125 km to spawn (Breeser et al. 1988). Burbot in the Kootenai River are thought to have traveled up to 120 km from Kootenay Lake, to spawn in tributaries in Idaho. Prior to the closure of Libby Dam, winter was the most environmentally stable time of the year with flows at their lowest for the Kootenai River. Burbot are weak swimmers and have low endurance (Jones et al. 1974); thus, it is reasonable that increased flow and velocity could affect spawning migration.

Any factor that would affect burbot in Kootenay Lake would also affect fish in the river because they are of the same genetic stock and have similar life history patterns (Paragamian et al. 1999). Also, recapture records of tagged fish (Partridge 1983) and sonic telemetry (Paragamian 1994) supported the position that this population is comprised of fluvial and adfluvial burbot that ascend the river in winter to spawn.

Within any given day, flow from Libby Dam can range from 113 m^3/s to 765 m^3/s depending on power demands. Disruption to spawning migrations of burbot likely contributed to failed spawning, reduced year-class success, and lost stocks of burbot, which may have had an affinity to specific spawning tributaries or reaches. In a companion study, technicians captured five post-spawn female burbot with unspawned eggs and several unspawned males (Paragamian 1995; Paragamian and Whitman 1996, 1999), suggesting a segment of the adult population is failing to spawn.

My study began with an objective of documenting burbot movement and spawning behavior using sonic telemetry (1994–1995) and continued with the objective of determining the effects of water management on burbot migrations. To test the null hypothesis that high flows and velocities created by discharge from Libby Dam for power production and floodwater control do not disrupt burbot spawning migrations, I studied the changes and differences in winter flows and velocities in selected reaches of the Kootenai River, and the response of burbot to varying flow conditions. My goal was to provide information that would be useful to the management and eventual recovery of burbot in Idaho and British Columbia.

Study Area

The Kootenai River is the second largest tributary to the Columbia River, the river originates in Kootenay National Park, British Columbia, in the Canadian Rockies, and has a drainage of 49,987 km^2 (Bonde and Bush 1975). From the

Canadian Rockies the river traverses south into Montana. Near Jennings, Montana, the river is impounded forming Lake Koocanusa. From Libby Dam, the river turns west, then northwest into Idaho, then north into British Columbia and Kootenay Lake. The river drains Kootenay Lake through the West Arm, and eventually joins the Columbia River near Castlegar, British Columbia. My study area was the reach of the Kootenai River from Bonners Ferry, Idaho, to Kootenay Lake, British Columbia (the South Arm of Kootenay Lake) and the lower Goat River, British Columbia.

Methods

Kootenai River Flow, Velocity, and Temperature

Daily flow from Libby Dam and water temperature for the Kootenai River were obtained from USACE and the U.S. Geological Survey (USGS) office in Sandpoint, Idaho. Prior to the onset of burbot sampling, from autumn 1995 through 1997, a conditional agreement was formulated with the Bonneville Power Administration (BPA) and USACE to provide experimental minimum flows (tests) for burbot pre-spawn migrations. There were to be three test discharge ($113 m^3/s$) replicates from Libby Dam of approximately 5-d duration each in November, December, and January for the winters of 1995–1996, 1996–1997, and 1997–1998. I hypothesized that these minimum test flows would allow burbot to move upstream by replicating pre-dam winter flow. In turn, I expected that the return of higher flows for power production or flood control after each minimum test flow would inhibit upstream movement or compel burbot to move downstream. Each replicate would also have a control, a condition of normal flow management for power production or flood control. I used Chi-square analysis to detect differences in burbot movement during flow tests and the controls (treatments), the significance level was set at $P \leq 0.01$. I evaluated daily movement in three categories: no movement, upstream, and downstream; they were coded 0, 1, and -1, respectively. Burbot movement was interpreted as ≥ 1.0 km in 1994–1995 and ≥ 0.1 km during the 1995–1998 studies. Telemetry data sets were combined and analyzed by replicate (i.e., November, December, and January). Daily water temperatures were also monitored with Stowaway XI temperature loggers in the Kootenai and Goat rivers, British Columbia, during various study seasons from November 1994 through 1998.

Some locations in the Kootenai River may become velocity barriers to burbot, at low compared to high flows from Libby Dam. Thus, the river was segmented into three reaches based on hydraulic controls; reach 1 – rkm 120-132 (downstream of the East Channel), reach 2 – rkm 133-152 (downstream from the mouth of the Goat River), and reach 3 – rkm 153-175 (from the Goat River to 5 km above the Idaho/British Columbia border to Smith Creek) (Paragamian et al. 2000). Using a table of random numbers, two rkm locations within each segment were selected where velocities would be measured. Velocities were measured approximately 15 cm above the river bottom using a Gurley 2030R flow meter suspended by a rope with a 0.67 or 0.84 kg lead weight attached. Mean bottom velocities were calculated for 5– min measurements at five evenly spaced points along each transect. On December 21, 1995 (high flow from Libby Dam) velocities were measured and repeated on February 16, 1996, at a lower flow. Average discharge was calculated for Porthill, Idaho (rkm 170), and a location representative of flow for the primary study reach. I used analysis of variance (ANOVA) to test for differences in velocities at the two discharge rates.

Sampling Adult Burbot

Technicians sampled burbot in the Kootenai River in Idaho and British Columbia, (rkm 120 to 178) in anticipation of intercepting burbot moving from Kootenay Lake and the lower river to their historic spawning areas. Burbot were usually sampled from November through April each year (occasionally earlier or later) with seven to 12 hoop nets (Bernard et al. 1991) of two sizes: 3.06 and 3.66-m in length, 0.61 and 0.91-m in entrance diameter, respectively, and 25-cm bar mesh. Each net was baited with fish before deployment. Nets were checked every 24 to 72 h. Fish captured in hoop nets were identified, enumerated, measured in total length (TL) and weighed. All burbot were passive integrated transponder (PIT) tagged in the left cheek muscle and released.

Implanting Sonic Transmitters

Adult burbot selected for telemetry were surgically implanted with either a 420-d, 40-d, or 60-d sonic transmitter. Before surgical implantation burbot were anesthetized in about 25 mg tricaine methanesulfonate (MS-222)/L. Fish were then placed in a cradle (Courtois 1981) and continuously bathed with water and anesthetic. Sonic transmitters were implanted according to the procedures of Hart and Summerfelt (1975), and size of transmitter was apportioned to the size of burbot. Sonic transmitters of 420-d life expectancy were 60 mm in length, 16 mm in diameter, and weighed 8 g, while 60 and 40-d transmitters were 16 mm in diameter, 37 mm in length and weighed 4 g. Sex of most fish was determined during the surgery. After completion of surgery burbot were allowed a recovery period of at least 20 min and usually released at the capture location.

My study design was to compare burbot movement during low flow tests, intended to simulate natural winter flows prior to closure of Libby Dam, and normal unrestricted wintertime dam operations (the control treatments). Movements of burbot were studied throughout the year but intensity varied with the season; only autumn and winter movements are presented in this report. In general burbot were monitored once a week from April through September, several times a week during October, nearly daily from November through February, and daily several days prior to, during, and immediately after a flow test. When burbot were located by telemetry, depth was measured with an echo sounder, and nose velocity was measured within 15 cm of the bottom using a Marsh-McBirney 2000 electronic current meter. I used a chi-square test to detect for differences in movement and ANOVA to test for differences in nose velocities during various water management schemes (significance was set at $P \leq 0.01$).

Results

Kootenai River Flow and Velocities

The travel time for flow releases from Libby Dam to reach Porthill (rkm 170), Idaho is about 24 h. Velocity in the Kootenai River at Porthill, Idaho is reliant on flow from Libby Dam and the elevation of Kootenay Lake, British Columbia (Paragamian 1995). The lake is at a low elevation during the winter months at about 531.5 m sea level. Flows at Porthill, Idaho can be substantially higher than at Libby Dam, ranging from 155 to 1,566 m^3/s depending on water management and precipitation.

I obtained five discharge and velocity measurements collected at Copeland, Idaho, (rkm 190), and calculated a regression formula for the two variables (John Gralow, USGS, personal communication). An increase in discharge (Q) during the winter months creates a direct proportional increase in velocity (V), where: $V= 2.82 + bQ$ and $b= 0.078$ (slope). Thus, an increase in discharge of 28.3 m^3/s increases average mid-column velocity by 5 cm/s. This model is not valid after winter when Kootenay Lake elevation is increased and water is stored for recreation and hydropower production.

Six transects were examined for differences in bottom velocities at a high flow and a lower flow, two each from three river sections. Locations were rkms 125, 128, 146, 152, 157, and 158. Five measurements, at equal distances, were made across each transect; mean bottom velocities ($\pm$ standard deviation) for each transect were 50 ($\pm$18.2), 46 ($\pm$17.7), 57 ($\pm$7.9), 85 ($\pm$9.9), 50 ($\pm$20.1), and 51 ($\pm$14.4) cm/s during a flow of 991 m^3/s at Porthill (rkm 170), respectively, while at a flow of 453 m^3/s velocities were 24 ($\pm$8.2), 21 ($\pm$7.5), 24 ($\pm$7.8), 35 ($\pm$12.1), 28 ($\pm$5.5) and 31 ($\pm$4.0) cm/s, for the same transects, respectively. Discharge from Libby Dam was 742 and 201 m^3/s, respectively, when these measurements were made. I found significant differences ($P = 0.01$) in current velocities (ANOVA) between the high discharge (991 m^3/s) and the lower discharge (453 m^3/s). At near maximum discharge, I found significant differences in velocities between sites ($P = 0.0009$), but at lower discharge they were not significantly different (P = 0.088); further testing also indicated that the highest velocities during maximum discharge occurred at rkm 152 (P = 0.0015).

Burbot Catch

Hoop net captures of burbot from winter sampling during 1994–1995, 1995–1996, 1996–1997, and 1997–1998 resulted in the captures of 33, 27, 23, and 42 fish, respectively (Paragamian 1995; Paragamian and Whitman 1996; Paragamian and Whitman 1997; Paragamian and Whitman 1998). Catch per Unit effort was one fish /21.5 net days, one fish /18.2 net days, one fish /45.6 net days, one fish /33 net days for the four time periods, respectively. Burbot ranged in TL from 300 to 958 mm and weights of 272 to 4,086 g (Paragamian 1995; Paragamian and Whitman 1996, 1997, 1998).

Burbot Telemetry, River Flow, and Temperature

Winter 1994–1995. Technicians monitored 14 burbot with sonic transmitters during this study segment, including two burbot that were previously implanted with sonic transmitters (Paragamian 1994) and 12 implanted and released at capture sites in the British Columbia portion of the Kootenai River (Paragamian 1995). Six burbot were monitored during the pre-spawn period of November 24, 1994 through January 15, 1995. Initially, most burbot remained in deep pools in close proximity to release sites. River discharges at this time from Libby Dam were usually between 383 and 510 m^3/s (Figure 1). Temperature of the Kootenai River was 5°C. On two occasions, discharges from Libby Dam were reduced from about 510 to 113 m^3/s, on December 16, 1994 and January 11, 1995 (Figure 1). Temperature of the river remained at 5°C. On each occasion burbot moved upstream several km when discharge was reduced. Burbot drifted downstream when discharge increased to 510 m^3/s. Burbot returned to the vicinity of their release or were located further downstream. Burbot 96 had not been located since July 7, 1994, but was relocated in Crawford Bay of Kootenay Lake (rkm 85) on December 13, 1994. It was located at rkm 116 on January 1, 1995. Twelve burbot were monitored between January 15 and February 27, 1995. The most notable burbot movement occurred after January 27 when discharge was again reduced and stabilized at 113 m^3/s (Figure 1). Temperature of the Kootenai River was 4-5°C. Most burbot moved upstream to the confluence with the Goat River where the temperature was 1-2°C. At least three burbot ascended the Goat River (sonic codes 3433, 356, and 365) on several occasions during the spawning season (several gravid females were caught and males with flowing milt), but returned to the confluence with the Kootenai River. I measured temperature of the Goat and Kootenai rivers with a temperature probe and prepared a profile of the confluence of the rivers. Most burbot staged in the cooler mixing portion of the Kootenai River (Paragamian 1995).

The last two burbot to receive transmitters (sonic codes 446 and 3334) were captured at the confluence of the two rivers. They remained in that reach for several days then bypassed the Goat River in late February when the temperatures of the two rivers were the same (5°C). These two fish and burbot 96 eventually moved upstream into Idaho. Seven burbot were monitored during the post-spawn period, which began in mid-February. All 40-d transmitters had expired by this period. Burbot with sonic codes 96, 3334, and 446 continued their upstream journey, entering Idaho in early March. These burbot demonstrated no activity indicative of spawning behavior, although 3334 and 446 were ripe. When river temperature reached 7°C, several burbot became relatively sedentary and remained in deep pools. Concomitant to the cessation of burbot movement was a rise in river temperature and discharge. Burbot 3433 eventually drifted down the Goat River to the confluence with the Kootenai River and remained there. Burbot 356 remained in the Goat River, and 2246 remained in the lower Kootenai River (rkm 130 to 136). Burbot 446 reached rkm 191.9 (in Idaho) in late May and drifted downstream to rkm 186, while 3334 remained in a deep pool (25 m) at Parker Creek (rkm 190). Burbot 96 moved downstream in late March and was relocated on the east side of Kootenay Lake (rkm

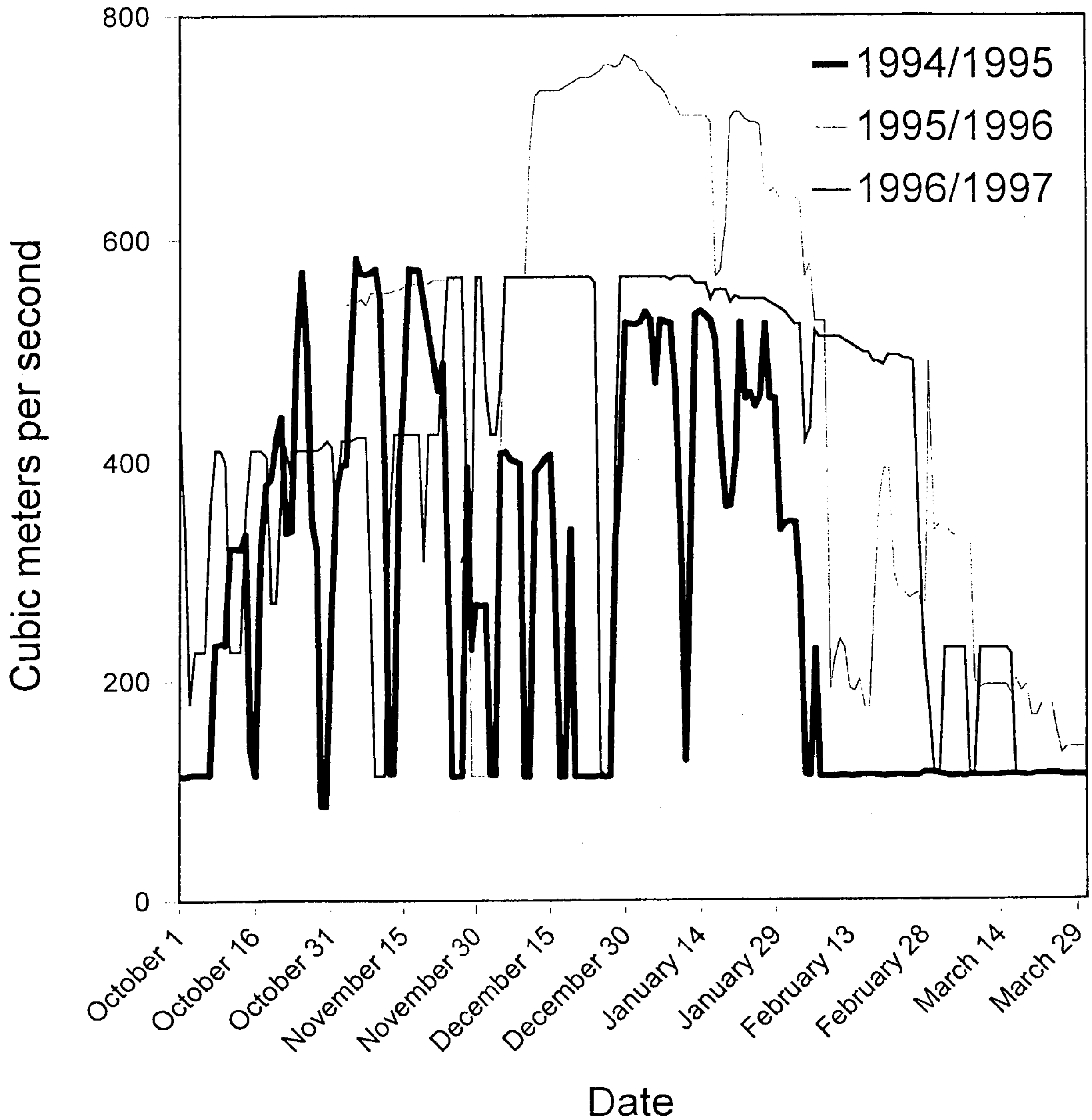

Figure 1. Mean daily discharge from Libby Dam, Kootenai River, October through March, 1994-1995, 1995-1996, and 1996-1997.

117.9) on June 25, while 446 and 3334 eventually entered the lake.

There were 17 observations when a burbot moved greater than 1 km between telemetry contacts during the winter of 1994–1995. Five burbot moved downstream when discharge decreased, two fish went down when discharge increased, ten moved upstream when discharge decreased, and none moved up when discharge increased. The Fisher Exact Test indicated a significant relation existed between burbot movement upstream and reduced flow (P = 0.0034).

Winter 1995–1996. Eight burbot were monitored between February 13 and February 26, 1996 (Paragamian and Whitman 1996) but extensive precipitation from autumn 1995 through winter 1995–1996 prohibited a migration test for burbot (Figure 1). Flow at Libby Dam ranged from 113 to 765 m^3/s from November 1995 through January 1996 but ranged from 162 m^3/s in early October 1995 to 1,204.6 m^3/s on December 14, 1996, at Porthill, Idaho (a location near the Goat River)

Winter 1996–1997. Technicians monitored movements of two burbot, implanted with transmitters the previous year, during the November 1996 flow test, sonic transmitters 374 and 357 (Paragamian and Whitman 1997). Burbot 374 progressively moved upstream from about rkm 133 to rkm 144 during October to a pool that was occupied by 357. Water temperature during this migration was about 10°C. Both burbot remained at about rkm 144 until the first test when flows were reduced from about 425 m^3/s on November 13, 1996 to 113 m^3/s on November 15 (Figure 1). Within 2 d of the initiation of the test flow, 374 moved from rkm 142.8 on November 15 to rkm 150.7 on November 22, while burbot 357 could not be located. When the normal operation of Libby Dam resumed on November 24 burbot 374 returned to rkm 144.0.

The second flow test began on December 25, 1996 and after 3 d was canceled by the USACE (Figure 1). Nine burbot had sonic transmitters at the initiation of this test(Paragamian and Whitman 1997). Six burbot were already in the immediate vicinity of the Goat River. The test did not result in any obvious burbot movement.

Burbot with sonic codes 374, 3334, and 96 were 8 or more km downstream from the Goat River during the second test. Despite the discharge of 567 m^3/s from Libby Dam after the test these burbot began a slow migration upstream and joined the main body of spawners between rkm 149 and 151. This trio of fish progressively moved upstream; 96 began November 29 while 374 and 3334 started in early January. I calculated minimum travel times for each burbot, taking burbot 3334 - 17 d to go 7.9 km (0.46 km/d), burbot 96 - 15 d to travel 8.7 km (0.58 km/d), and burbot 374 - 11 d to go 7.4 km (0.67 km/d).

Eleven burbot were monitored between February 1 and February 26. A request for a flow test just prior to the spawning period was denied by the USACE. Temperature of the Kootenai River ranged from 0 to 2.5°C. Telemetry indicated that burbot had gradually moved upstream to the mouth of the Goat River where at least four burbot with transmitters moved up the Goat River during the spawning season. Temperature of the Goat River ranged from 0 to 2.5°C during the spawning period. Flow in the Kootenai River from Libby Dam remained high during most of the spawning period but after burbot completed spawning the USACE reduced flows (Figure 1). Discharge during the last week in February was reduced to base flow of about 113 m^3/s, and remained low through March 17, 1997.

Winter 1997–1998. The USACE provided three flow tests during the winter 1997–1998, one in each replicate of November, December, and January. Technicians monitored five burbot during November, 1997 (Paragamian and Whitman 1998). Flows from Libby Dam during the control ranged from170 to 510 m^3/s (Figure 2) and water temperatures from 9 to 12°C. Little movement took place during the control interval. However, the most notable movement before November was that of 374 (monitored for the third consecutive season). This burbot had traveled from rkm 133 during late September to rkm 144.3, remained there until November 20, then traveled to rkm 150.7 when flow was about 450 m^3/s, stayed 2 d then returned to rkm 144 (Figure 2).

<u>November</u>. Technicians monitored the movement of five burbot during November; none moved >1 km. The first flow test started on November 28 and ended December 1 while the control was from November 13 through 27 (Figure 2). Technicians recorded a total of 43 telemetry contacts during November; nine records indicated burbot moved downstream, 11 records indicated upstream, and 23 records indicated no movement (Table 1). None of the five burbot moved >1 km although 20 records of short-range movement were recorded (<1.0 but $\geq$0.1 km).

<u>December</u>. The same five burbot were moni-

tored during the second replicate test, the last week in December. The December replicate included December 3 through 24 for the normal water management (control) and December 25 through December 30, 1997, for the test (Figure 2). Flows from Libby Dam during the December control ranged from 113 to 649 m^3/s (Figure 2), Kootenai River temperatures ranged from 4°C to 10°C. Temperature of the Goat River ranged from <1°C to 3°C. Flow on December 25 was reduced from 442 to 113 m^3/s. Technicians recorded 54 telemetry contacts with burbot during December; 16 records indicated downstream movement, 15 records indicated upstream movement, and 23 records indicated no movement (Table 1).

January. Eight burbot were monitored during January. The control treatment of normal winter water management was from December 31, 1997 through January 22, 1998. The third test began January 23 when flow from Libby Dam was reduced from 351 m^3/s to 113 m^3/s and ended January 29, 1998 (Figure 2). Flows from Libby Dam during January ranged from 113 to 360 m^3/s and temperatures ranged from <1°C to 5°C.

Technicians recorded a total of 103 telemetry contacts for analysis during January; 31 contacts showed movement downstream, 46 records indicated upstream movement, and 26 contacts indicated no movement (Table 1). There were 15 instances when burbot moved 1.0 km or more during the test treatment.

Power peaking (rapid increases and decreases in flow) was a frequent method of operation for Libby Dam by the USACE after the January test (Figure 2). Flow ranged from 113.3 to 587 m^3/s daily. Most burbot appeared to move with changes in flow, moving upstream then downstream, etc. For example, burbot 374 made three extensive journeys from rkm 144 to 154, back to 144 and then back to 153. At this same time migrations into the Goat River by spawning burbot occurred (about February 13) when temperature was 3.2°C. Five burbot were recorded in the Goat River but at least six of the 12 burbot tracked during this last session of study showed no behavioral traits indicative of spawning but were found to be moving frequently. After the spawning season all burbot moved downstream, and several entered Kootenay Lake.

Statistical Analysis.

Burbot movement (upstream and downstream) during flow tests of 1997–1998 occurred with nearly twice the frequency of those during the control (normal winter water management): 45% to 28%, (Table 1). Chi-square analysis indicated that burbot moved 0.1 km or more with significantly higher frequency during the flow tests as compared to control conditions (Pearson $\chi^2 = 8.913$; P = 0.012). Chi-square analysis also indicated burbot moved upstream ≥ 0.1 km with significantly greater frequency during the tests compared to controls (Pearson $\chi^2 = 6.739$; P = 0.009). Additional analysis indicated that there was no significant difference in the amount of burbot movement (up and downstream) between the three replicates (Person $\chi^2 = 9.81$; P = 0.04). There was no detectable difference in the direction of movement for the first two test replicates (Pearson $\chi^2 = 5.41$ and P = 0.067; Pearson $\chi^2 = 0.418$ and P = 0.811, respectively) however movement upstream during the January flow test was significantly higher than the control (Pearson $\chi^2 = 11.967$; P = 0.003).

Table 1. Telemetry results of burbot movement ≥0.1 km during three replicate studies with tests and controls, Kootenai River, 1997-1998. Percentages for each movement category are subtended.

Replicate	Direction of Movement							
	None		Upstream		Downstream		Totals	
	Test	Control	Test	Control	Test	Control	Test	Control
November	13 (30)	10 (23)	10 (23)	1 (<1)	4 (9)	5 (12)	27 (63)	16 (37)
December	7 (13)	16 (30)	6 (11)	9 (17)	5 (9)	11 (20)	18 (33)	36 (67)
January	5 (5)	21 (20)	27 (26)	19 (18)	18 (17)	13 (13)	50 (49)	53 (51)

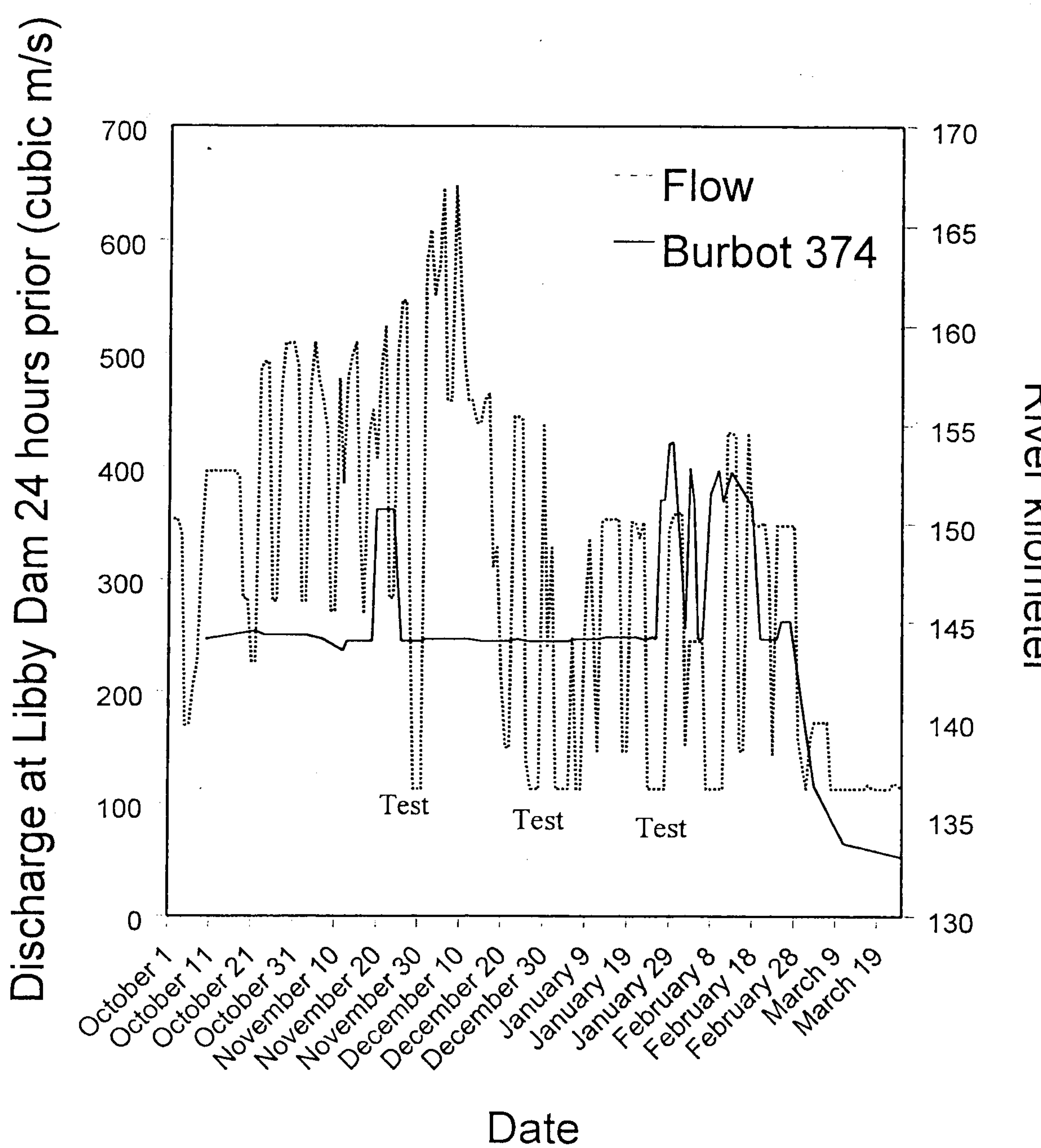

Figure 2. Mean daily discharge from Libby Dam (24 h prior to date), Kootenai River, October through March 1997-1998, showing power peaking, flow tests, and movement (locations by rkm) of a burbot tagged with a sonic transmitter with code 374. It takes approximately 24 h for water to move from Libby Dam to rkm 170, the Idaho/British Columbia border.

Power analysis, using an approach suggested by Zar (1984), for burbot movement detection indicated that 168 observations would be required at power = 95% (1 – beta = 0.95) and chance of a type-1 error = 5% (alpha = 0.05). For power of 95% and error of 1%, 227 observations would be needed, for power of 99% and error of 5%, 233 observations would be needed, and for power of 99% and error of 1%, 302 observations were necessary.

Nose velocities were measured at the locations of 13 burbot during the winter study of 1997–1998. Velocities measured during the normal dam operation averaged 11.85 cm/s (SD = 9.08, N = 40) while those measured during the tests averaged 7.46 cm/s (SD = 5.23, N = 59). One-way ANOVA testing indicated nose velocities measured during the low flow tests were significantly lower than the control days of normal dam operation (F with 1, 97 DF; P = 0.01; F = 6.96; test F = 9.28).

Discussion

Burbot spawning migration in both activity and upstream passage was disrupted by elevated winter flows and velocities. Elevated flows were due to hydropower production and evacuation of water from Lake Koocanusa for flood control, and were directly related to increased velocities. Winter flow in the Kootenai River is now three to four times greater than it was historically, when flow conditions were relatively stable. The specific effect of this disruption is unknown, but may have reduced spawning fitness, timing of burbot spawning synchrony, affected vitellegenin synthesis, and reduced stamina. One or all of these possible reasons could have been sufficient to reduce spawning success and reduce recruitment to sustain the fishery.

Examination of the physical characteristics of the Kootenai River indicated that migrations of burbot might be further affected when increased flows change some reaches into velocity barriers or difficult passage locations. Telemetry studies of 1994–1996 indicated that few burbot moved above rkm 152. Velocity measurements during winter 1995–1996 showed that this reach had significantly higher velocities than other randomly selected sites when discharge was 991 m^3/s at Porthill. Other locations in the river may be similar or more severe. This fact suggests future management of the river for burbot migrations may also need to consider velocities at specific locations when discharge is reduced. Difficult passage areas have also been a concern for the spawning migration of some stocks of sockeye salmon *Oncorhynchus nerka* (Talbot and Jackson 1950; Pearse 1992; Hinch et al. 1996) in unregulated reaches of the Fraser River, British Columbia.

Highly fluctuating flows appeared to generate confusing migration cues and continuously disrupted upstream burbot migrations. Most burbot demonstrated repeated sequences of movement upstream, no movement, and/or fall back during the winter of 1994–1995 and 1997–1998 when power peaking was a common water management factor. Daily differences in flow from Libby Dam during winter can range up to 652 m^3/s. Burbot are winter spawners and under pre-Libby Dam conditions this was the most environmentally stable time of the year. Jones et al. (1974) found that burbot had the lowest swimming stamina of 20 species studied; velocities higher than 24 cm/s were too great for even the largest burbot to maintain a stable position. I also found that burbot nose velocities were significantly higher ($P < 0.01$) during normal winter operation (controls) of Libby Dam than during low flow tests. Burbot intolerance to high velocities was also shown for adults during a spawning migration into the Duncan River, British Columbia (C. Spence, British Columbia Ministry of Environment Lands and Parks, personal communication). The river flows into Duncan Lake, a historically natural lake that now has a dam at the outlet. Burbot monitored with radio telemetry ascended the Duncan River and occupied a low velocity reach of river just upstream of the lake. When the lake was lowered, velocities in the lower river increased as the back watering effect was reduced, and burbot moved progressively downstream. Burbot locations had near-bottom water velocities averaging 13 cm/s, while velocities in vacated habitats upstream averaged 50 cm/s. Malinin (1971) reported that burbot moved slowly during their spawning migration, at speeds that did not exceed 10 m/min, and remained in the river thalweg where current velocities were comparatively low (e.g., 30–40 cm/s). Breeser et al. (1988) monitored burbot spawning movement in an unregulated Alaskan river but they did not report long periods of little or no movement nor fall back. Breeser et al. (1988) also reported that some burbot in the river system they studied moved into smaller tributaries in late summer after water velocities had dropped. Investigations of sockeye salmon, a species that is well suited to long distance migrations, have shown that high flows or velocities can create high energy costs and result in longer travel times (Hinch and Rand 1998; Rand and Hinch 1998).

Burbot are thought to be highly synchronous in their spawning (Becker 1983; Arndt and Hutchinson 2000; Evenson 2000). Burbot spawning synchrony in the Kootenai River may have been disrupted in several ways. I found that burbot travel time was slower during flows higher than 113 m^3/s. Telemetry findings during winter 1994–1995 indicated three burbot that migrated to Idaho, from Kootenay Lake and the Kootenai River in British Columbia, did not arrive until a month or more after the spawning season and when water temperatures were above 7°C, warmer than spawning temperatures (Becker 1983). These burbot demonstrated no behavior indicative of spawning. Inhibition of spawning movement may also explain why five unspawned females, in a stage of resorbing eggs, and several males were caught that were either flowing milt or were unspawned during late February and March during several different years of study (Paragamian 1995; Paragamian and Whitman 1996, 1999). Six of 12 burbot monitored during the winter of 1997–1998 are believed to have failed to spawn. Failure to spawn may have been due to excessive stress caused by changing flows of power peaking and flood control. Rand and Hinch (1998) estimated that 8% of sockeye salmon in the Fraser River, British Columbia, might have run the risk of in-river mortality because of energy depletion. Di Stefano et al. (1997) studied blood parameters in a reproductively dysfunctional walleye *Stizostedion vitreum* population downstream of a hydropower dam in Missouri. They found evidence to suggest reproductive failures in the walleye were due to stress and possibly related to water temperature and flow changes caused by power peaking or the absence of requisite environmental signals necessary for spawning or both.

Burbot are known to travel long distances to spawn in some river systems (Breeser et al. 1988). In my study at least one burbot traveled over 120 km during the spawning migration period. Arndt and Hutchinson (2000) found that peak spawning of burbot in a tributary to Columbia Lake, British Columbia, occurred within 2–3 d of the same day of the year three of the four years of study. Thus, for burbot, which are naturally slow moving, to reach spawning tributaries in Idaho may take nearly a month of travel from Kootenay Lake and any disruption is likely to affect arrival timing to spawning areas.

Movement of burbot was significantly higher ($P < 0.01$) during January than other months of study. The motivation to move more during January was probably a result of the proximity to spawning, which usually occurred during the first two weeks of February. However, my test may have also been affected by sample size, (103 observations in January compared to 54 in December), but there were also more upstream observations in December than downstream. Breeser et al. (1988) found that burbot moved extensive distances but the most movement occurred during the spawning season.

Warmer winter temperatures in the Kootenai River may not have affected burbot spawning synchrony but it could have masked the location of spawning tributaries. During the winters of 1994–1995 burbot were attracted to the colder water of the Goat River compared to the Kootenai River, 1° and 4°C, respectively. Soon after this observation burbot ascended the Goat River to spawn but when the temperature of the two rivers was similar several days later, three additional burbot bypassed the Goat River on a suspected spawning journey into Idaho (previously noted). The Goat River is the largest tributary to the Kootenai River between Bonners Ferry and Kootenay Lake. The Goat River also has the largest cold-water input. Although other tributaries were substantially cooler than the Kootenai River and because of a backwater effect, because of high flows, their low volume was diluted by the higher flow in the river (Paragamian and Whitman 1996, 1997, 1998, 1999). Arndt and Hutchinson (2000) found that the lowest escapement of burbot spawners to a tributary of Columbia Lake, British Columbia, occurred during a season when water temperature was several degrees warmer than other years of record.

Modification of present flood rule curves by the USACE and the return of flow in the Kootenai River during January and the first week in February (5 weeks) to pre-Libby Dam levels of about 200 m^3/s may provide sufficient change to help recover burbot. Burbot would thus be conceded a travel corridor similar to natural pre-dam conditions and allowed to migrate unimpeded to tributaries in Idaho. However, it will also be necessary to make additional ecosystem improvements to help restore pre-Libby Dam conditions. Finally, the loss of nutrients might also have played a role in the collapse of burbot (Paragamian 1994). It may also be necessary to artificially refound spawning runs to specific tributaries, using adult fish of similar genetic composition and life history.

The collapse of burbot populations below dams after their construction is a common phenomenon in the northwestern USA and in western Canada (McPhail 1994). Information from this study may be useful to recovery efforts of other burbot populations. Because most of the dams constructed in western North America are for flood control and/or hydropower, it seems likely that the reasons for the collapse of these fisheries may be similar.

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